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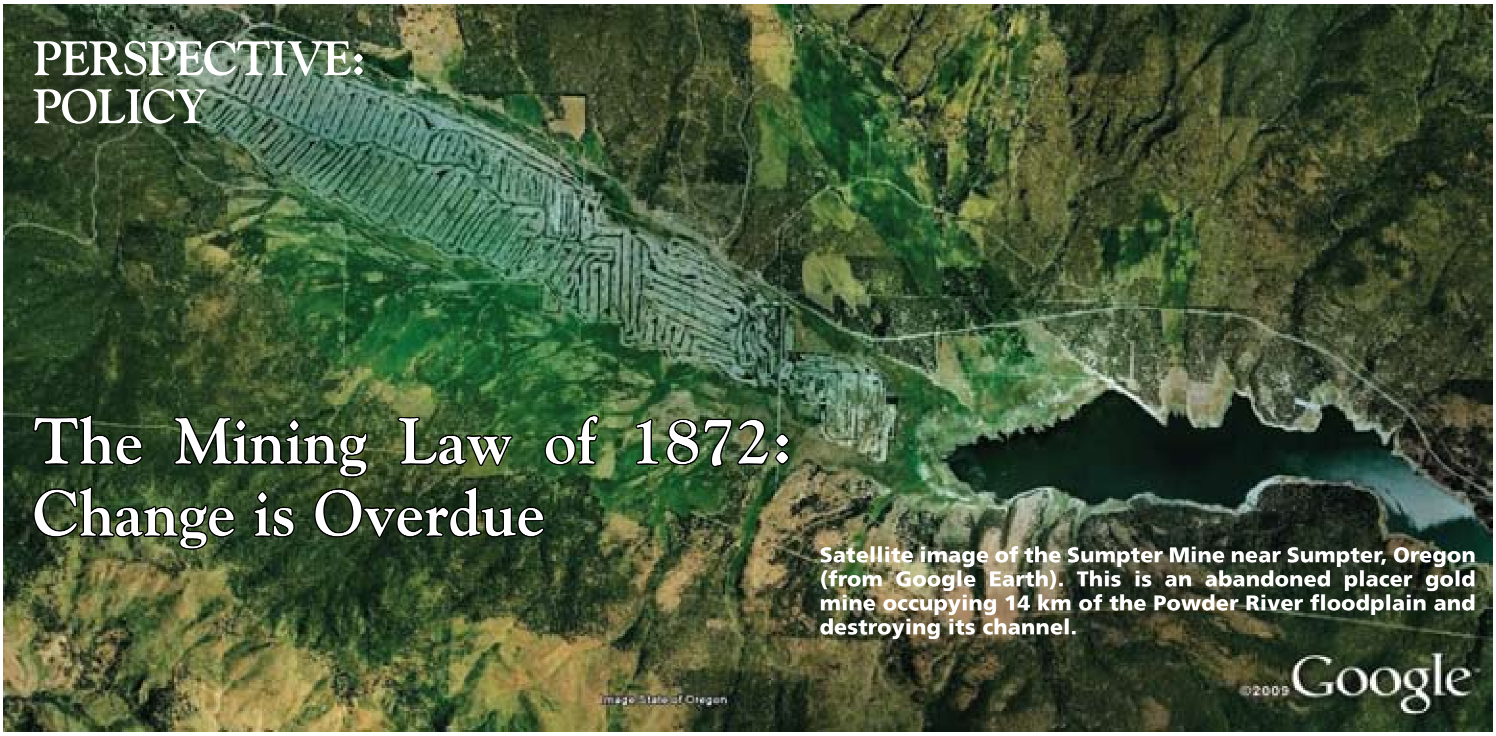

The Mining Law of 1872: Change is Overdue

Satellite image of the Sumpter Mine near Sumpter, Oregon (from Google Earth). This is an abandoned placer gold mine occupying 14 km of the Powder River floodplain and destroying its channel.

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ABSTRACT: Hardrock mining for metals has been, and is, an economically important land use in all western U.S. states. However, metals contamination associated with mining can be highly toxic to aquatic life, the composition of metal-bearing rock often leads to acid mine drainage and increased concentrations of dissolved metals, and mine-related disruptions to soil and water often produce excess fine sediments and altered stream flows. Such environmental degradation leads to large numbers of perpetually polluted streams and impaired aquatic life and fisheries. The primary U.S. law governing mining, the General Mining Law of 1872, was passed during the pick-and-shovel era to encourage economic growth; however, modern mining processes are massive in extent, highly mechanized, and incorporate additional toxic chemicals for leaching metals from ores. We provide an overview of hardrock mining impacts to aquatic life, a set of mining case studies, and suggestions for amending U.S. mining law. Our hope is that this article will lead to improved management and rehabilitation of existing mine sites and sufficient protections for the aquatic life and fisheries likely to be disturbed by future mines.

La ley de minería de 1872: un cambio retrasado

RESUMEN: la minería metalúrgica subterránea ha sido, y aún es, una actividad económicamente importante en cuanto a uso de suelo en los estados del oeste de los Estados Unidos de Norteamérica. Sin embargo, la contaminación por metales asociada a la minería puede ser altamente tóxica para la vida acuática, la composición de las rocas que contienen metales suele derivar en drenaje ácido de mina e incrementar la concentración de metales disueltos y las alteraciones en el suelo y agua relacionados con la minería pueden producir un exceso de sedimentos finos que alteran el cauce de los ríos. Tal degradación ambiental da lugar a un considerable número de cauces permanentemente contaminados, lo que pone en peligro tanto a la vida acuática como a las pesquerías. La ley directriz de minería de los Estados Unidos de Norteamérica, La Ley General de Minería de 1872, fue decretada durante la época de "pico y pala" con el fin de promover el crecimiento económico; no obstante, los actuales procesos de minería son extensivos, altamente mecanizados e incorporan químicos tóxicos para lixiviar metales a partir de minerales. En este trabajo se presenta una revisión de los impactos de la minería subterránea en la vida acuática, un grupo de minas como casos de estudio y sugerencias para modificar la Ley de Minería de los Estados Unidos de Norteamérica. Nuestra esperanza es que la presente contribución de lugar a un mejoramiento en el manejo y rehabilitación de las minas existentes y a suficientes medidas de protección para la vida acuática y las pesquerías que puedan ser alteradas por la explotación de más minas en el futuro.

Introduction

The U.S. General Mining Law of 1872 governs mineral extraction (e.g., uranium, copper, gold, etc.) on about 147 million ha of public lands in the western United States, an area equal to approximately 38% of the nation (National Academy of Sciences 1999). The 1872 law makes mining a priority use on most of these lands, guarantees priority rights for minerals extraction, and was originally intended to encourage economic growth by conveying public lands to private owners for the purpose of mineral extraction. In practice, applications to mine public lands often cannot be denied despite deleterious impacts to other resources. Under this law, a miner can purchase (patent) the surface estate and mineral rights to federal land for $1–2/ha by demonstrating the presence of a valuable mineral deposit. Currently, there is a year-to-year moratorium on new patents but this is not a permanent solution. Due diligence, i.e., $100 of annual spending on mining activity, is required, but even if millions of dollars worth of minerals are extracted from these public lands, no fees or royalties are required in return (Bakken 2008), resulting in an estimated annual loss of revenue of $160 million to the U.S. government (Pew Foundation 2009). This law remains in effect, despite serious environmental and economic issues caused by hardrock mining practices and a shift in priority use on federal lands. In addition to the Mining Law of 1872, other federal laws apply to regulate the effects of hardrock mining (e.g., Clean Water Act, National Environmental Protection Act). However, because of the magnitude of the issue and the antiquated nature and primacy of the Mining Law of 1872 a comprehensive reform of that law is needed. Our focus in this article is hardrock metal mining, the extraction of metals found in hard rock geological formations. Placer mining of alluvial deposits is also governed under the Mining Law of 1872 and is associated with damage to aquatic life (e.g., Sumpter Mine on the Powder River, Oregon), but is not a focus of this article. Related concerns also pertain to surface coal mining, which is regulated by a different under-protective law (Surface Mining Control and Reclamation Act of 1977).

Impacts to fisheries from hardrock metal mining result from both abandoned and active mines. The U.S. Environmental Protection Agency (USEPA) estimates that there are 500,000 abandoned mines in the United States; 40% of western headwater streams are polluted from mining. Clean-up costs are estimated at $32–72 billion (USEPA 2000). Under the Mining Law of 1872, mining companies are not required to provide adequate insurance for clean up and reclamation of federal lands. Perhaps more troubling, many mines slated for clean-up require long-term or perpetual water treatment (USEPA 2004). Such ongoing water contamination threatens drinking water supplies, valuable fisheries, wildlife, agriculture, recreation, tourism, human health, and industries that rely on clean water. In effect, the 1872 law shifts wealth from the United States public to mining companies, and shifts liability from those companies to the taxpayer (USEPA 2004).

Most high-grade, accessible mineral deposits in the United States are already exploited; therefore, new hardrock mining ventures generally focus on low-grade ore deposits. The Mining Law of 1872 and relatively high prices allow for low-grade ore to be marginally profitable because mining corporations are not required to purchase sufficient reclamation insurance. If there is a disaster or massive reclamation expense, they can simply abandon the site and declare bankruptcy. The quantity of waste material generated can be massive, with mine waste areas covering hundreds of hectares and containing tens to hundreds of millions of tons of spoil. For example, the proposed Pebble Mine in the headwaters of Bristol Bay, Alaska, has an estimated mineral resource of less than 1% copper, gold, and molybdenum; 99% of the estimated 7.5 billion tons to be excavated are projected to be acidic waste that will remain on site in perpetuity (www.dnr.state.ak.us/mlw/mining/largemine/pebble/index.htm). The processes used to access and extract minerals in modern mining operations create extensive ecosystem disturbance that can lead to long-term adverse effects to ground water, aquifers, surface water, aquatic resources, terrestrial vegetation, wildlife, soils, air, and cultural resources. Typical environmental effects are associated with:

Access. In remote areas, road construction and increased human activity lead to a variety of ecological effects, either directly related to the roads or the increased number of people accessing the area.

Earth disturbance. To reach and extract desired minerals, most hardrock mining operations displace massive amounts of soil and rock, either at the surface or underground.

Waste piles. Waste rock, spent ore, or tailings are generally disposed of in large heaps, ponds, or tailing impoundments, which can occupy hundreds of hectares. If these facilities are poorly designed, improperly constructed, or prematurely abandoned, their failure can lead to long-term contamination of surface and ground water.

Toxic dust. Toxic dust from dried-up tailings ponds, open pits, roads, and trucks hauling crushed ore can be carried by wind far from the mine site and contaminate surface and ground water as well as air and terrestrial vegetation.

Toxic processing chemicals. Desired metals are extracted or leached using chemicals that can be toxic if released into the environment (e.g., sodium cyanide, mercury, sulfuric acid, xanthates).

Acid mine drainage (AMD). Exposure of sulfide minerals, frequently associated with metallic ores, can create acidic conditions and leach metals into local waters. This AMD constitutes one of the most serious and common water pollution problems associated with mining (USEPA 1994; Sherlock et al. 1995); perpetual treatment may be required.

Water and soil contamination. Even without acidic conditions, metals can be discharged from mine sites and enter surface water, ground water, and soils. This can cause significant damage to aquatic life, vegetation, and terrestrial wildlife, and poses a hazard for human health. Toxic loading of stream waters can alter the assemblage structure of invertebrates (Clements et al. 2000; Maret et al. 2003), invertebrates and fish (Hughes 1985), and fish behavior (DeCicco 1990). Those toxic metals also contaminate water and sediment and bioaccumulate in fish tissues (Harper 2009), leading to reduced fitness or death (National Academy of Sciences 1999).

Flow alteration. Impoundment of water and stream diversions can lead to loss of habitat for fish spawning and rearing.

The perception that modern mining techniques are vastly improved over historic methods was recently challenged by a comprehensive study of modern U.S. mines (Maest et al. 2005; Kuipers et al. 2006). For example, the study compared predicted water quality impacts to observed impacts found at a sample of 25 U.S. mines. In summary:

100% of mines predicted compliance with water quality standards prior to operations (assuming pre-operations water quality was in compliance).
76% of mines exceeded water quality criteria as a result of mining.
64% of mines employed mitigation measures that failed to prevent water quality contamination.

Examples of mining impacts on aquatic resources

Without responsible laws and policy, and adequate reclamation and remediation, existing and future hardrock mines pose a risk to fish-bearing waters, in addition to the legacy effects of abandoned mines. Numerous examples of valuable fisheries and aquatic ecosystems harmed by hardrock mining exist across the western United States. High metals prices and demand for raw materials have created a modern minerals rush, with existing mines expanding, new claims being staked on public lands, and old mines reopening. Select case studies are presented to exemplify frequent compatibility issues existing between fisheries resource conservation and hardrock mining. These are not rare occurrences; USEPA (2004) identified 156 hardrock mining sites in the United States with past or potential Superfund liabilities of $1 million or more each.

Alaska

Red Dog Mine

The Red Dog Mine is located in northwest Alaska, near Kotzebue, and has been in operation since 1989 (www.reddogalaska.com/). It is the largest zinc mine in the world, providing 10% of the world's zinc (http://northern.org/news/epa-rescinds-key-red-dog-mine-permit-limits; Szumigala et al. 2009), and has polluted Wulik River tributaries with zinc, lead, selenium, and cyanide. The Wulik River is the drinking water source for the native village of Kivalina and the location of a subsistence and sport fishery for Pacific salmon (*Oncorhynchus* spp.), Dolly Varden (*Salvelinus malma*), and Arctic grayling (*Thymallus arcticus*). Observed shifts in overwintering sites by Dolly Varden were reported by DeCicco (1990; 1996), coincident with increased metals in 1989. Natural levels of zinc are high (approximately 10 times the state water quality standards in 1989), but rose to as much as 200 times higher once mining began in 1989. Because natural levels of minerals are high, the regulatory framework for water quality on Red Dog Mine is complex. However, tools to differentiate naturally-occurring metals vs. anthropogenic sources are available (Kelly and Hudson 2007). High levels of metals associated with dust from haul trucks were measured as highly toxic and are potentially affecting the entire watershed (Ford and Hasselbach 2001). In addition, the mine has been subject to numerous regulatory actions and currently the permit to expand the mine has been rescinded. In 1991, the mine operator was cited for 134 violations of effluent limitations for metals and pH, and spent $11 million in 1991 to route Red Dog Creek around the mine and isolate it from seepage (USEPA 1991). Dead fish from the Wulik River, approximately 40 km downstream from the mine, were discovered periodically by the public (ADNR 2004), suggesting that water chemistry samples were insufficiently protective of aquatic life, which is similar to what was concluded by Ohio EPA (1990) in its comparison of chemical and biological criteria. The mine operators paid a $1.7 million penalty for illegal discharges in 1997, and in 2008 agreed to pipe mine wastes to the Chukchi Sea or pay an additional $8–20 million penalty.

Kensington Mine

The U.S. Army Corps of Engineers approved a permit application by Coeur Alaska to deposit up to 4.5 million tons of gold mine tailings from the Kensington Mine into Lower Slate Lake, Alaska, which hosts Dolly Varden and threespine stickleback (*Gasterosteus aculeatus*). The permit was approved even though Coeur Alaska agreed in its application that these two fish species would be extirpated from the lake by the waste. The U.S. Supreme Court upheld the Corps' decision in 2009 because of conflicting and confounding laws and regulations governing when mine waste is treated as fill or as pollutant discharge (*Couer Alaska, Inc. vs. Southeast Alaska Conservation Council*). The Supreme Court decision sets a legal precedent that may allow other mining operations to avoid adherence with Clean Water Act water quality criteria by petitioning the Corps of Engineers to redefine pollutant-containing waste material as fill. This is a key issue also related to mountaintop removal and valley fill for surface coal mining in the Appalachians (USEPA 2009b).

Arizona

Pinto Valley Mine

Pinto Valley Mine, an open pit copper mine in Gila County, began operations in 1972, withdrawing water from the local aquifer and discharging to an intermittent section of Pinto Creek. Copper and zinc concentrations exceeded Arizona aquatic life criteria, metals bioaccumulated, and fine sediments buried natural substrates by an average of 15 cm, converting the reach from riffles and pools to a homogeneous run. Mountain sucker (*Catostomus platyrhynchus*) and western mosquitofish (*Gambusia affinis*) were greatly reduced in the polluted reach and 20 macroinvertebrate taxa were eliminated within 4 years. During spills and high flow events, dissolved metals were sufficient to kill fish (Lewis and Burraychak 1979).

California

Iron Mountain Mine

Iron Mountain Mine was a copper mine in operation from the 1860s through 1963 in northern California, near Redding (www.epa.gov/superfund/eparecovery/iron_mountain.html). This mine became infamous for developing the most acidic water in the world with a pH of -3.6 and it is estimated that the AMD from this site will persist for at least 3,000 years (www.epa.gov/aml/tech/imm.pdf; National Academy of Sciences 1999). Water from Iron Mountain Mine entered adjacent streams and eventually Keswick Reservoir, a run-of-the-river reservoir on the Sacramento River. Streams draining Iron Mountain Mine are devoid of aquatic life downstream of the mine. As early as 1900, the California Fish Commission investigated fish kills in the Sacramento River attributed to pollution from the mine. State records document more than 20 fish-kill events in the Sacramento River downstream of Iron Mountain Mine since 1963. AMD from Iron Mountain Mine killed 100,000 or more fish on separate occasions in 1955, 1963, and 1964; and at least 47,000 trout died during a one-week period in 1967. The AMD from Iron Mountain Mine has harmed four runs of Chinook salmon (*O. tshawytscha*), steelhead (*O. mykiss*), and resident rainbow trout, as well as hundreds of benthic species (Hallock and Rectenwald 1990). The National Marine Fisheries Service lists the winter-run and spring-run Chinook salmon, which spawn in the Sacramento River near Redding, as endangered and threatened, respectively, pursuant to the Endangered Species Act. Iron Mountain Mine is now a Superfund site.

Leviathan Mine

Leviathan Mine began operations in 1863 on the eastern side of the Sierra Nevada (Alpine County), and from 1952 to 1962 (www.epa.gov/superfund/sites/npl/nar1580.htm) consisted of an open pit mine covering about 101 ha. Acid mine drainage developed during operations; additional contaminants include aluminum, arsenic, chromium, copper, iron, nickel, selenium, and zinc. The AMD flows into Leviathan Creek at numerous points, devastating aquatic life until Leviathan Creek joins the East Fork of the Carson River. For most of the year, roughly half of the flow in Leviathan Creek is composed of AMD (http://yosemite.epa.gov/r9/sfund/r9sfdocw.nsf/84e3d3f7480943378825723300794f02/93009e9e968d570788257007005e9445!OpenDocument). The Aspen Seep releases AMD containing elevated levels of aluminum, copper, iron, and nickel into Aspen Creek. Each of these metals has historically exceeded EPA water quality criteria for aquatic life by over 500 times. Since 1983, California has invested millions of dollars to contour the pit and surrounding waste piles, channel Leviathan Creek around the major disturbed area, and capture the most concentrated flow in a series of ponds. Leviathan Mine is now a Superfund site.

Colorado

Summitville Mine

The South Mountain mineral reserves, located in southwestern Colorado near Del Norte, were mined from 1984 to 1992 as a gold and silver open pit heap leach operation. Acid mine drainage and cyanide releases from the open-pit mine and heap leach pad were lethal to all fish and aquatic life for 29 km downstream in the Alamosa River (www.epa.gov/region8/superfund/co/summitville/). Summitville Mine was determined by the U.S. Geological Survey (USGS) to be the dominant source of aluminum, copper, iron, manganese, zinc, and acidity in the Alamosa River (http://pubs.usgs.gov/of/1995/ofr-95-0023/summit.htm#King.1995a). As of 2005, water quality criteria for aquatic life were regularly exceeded, partly as a result of contaminated ground water inputs as well as release of contaminated water from the Summitville Dam impoundment. The mine operator declared bankruptcy in 1992 and the USEPA assumed control of the site as part of an Emergency Response Removal Action. The mine was listed as a Superfund site in 1994; cleanup costs have exceeded $150 million and perpetual water treatment is required.

Idaho

Coeur d'Alene Mining District

The Coeur d'Alene Mining District is located in the panhandle of northern Idaho. This mining area has produced lead, silver, gold, and zinc from the 1880s to the present. Widespread contamination of water and soils resulted from numerous mining operations. The South Fork Coeur d'Alene River and tributaries, Coeur d'Alene River and lateral lakes, Lake Coeur d'Alene, and the Spokane River are associated with the Bunker Hill-Coeur d'Alene Basin Superfund site, a "mining megasite" (National Academy of Sciences 1999). Tributaries to the North Fork Coeur d'Alene River are also water quality impaired, associated with mining. Water quality, biological, and hydrologic conditions have been affected, and reduced native species diversity and abundance have been measured within study areas downstream of mined areas compared to non-mined sites because of metals contamination (Ellis 1940; Hoiland et al. 1994; Maret and MacCoy 2002). Metals-contaminated water also has impaired westslope cutthroat trout (*O. clarkii lewisi*) fisheries and contributed to the extirpation of bull trout (*Salvelinus confluentus*) from the Coeur d'Alene Basin upstream of Lake Coeur d'Alene. Spawning migrations of introduced Chinook salmon have also been affected, which has implications for their long-term sustainability and survival (Goldstein et al. 1999). The Idaho Department of Health and Welfare (IDHW 2003) issued a fish consumption advisory for Lake Coeur d'Alene based on lead, arsenic, and mercury concentrations in fish flesh. The advisory cites historical mining practices in the Coeur d'Alene watershed as the source of the contaminated soil and water in the area. The fishes sampled included bullhead (*Ameiurus* sp.), kokanee (*O. nerka*), and largemouth bass (*Micropterus salmoides*). Those species were chosen because they are consumed extensively by tribal anglers (IDDH 2003). Cleanup costs to the taxpayers as of 2001 were $212 million (Steele 2001). Recent analyses estimate attainment of water quality goals in just the upper basin of this mining district could take several centuries at costs of $1–2 billion (http://yosemite.epa.gov/R10/CLEANUP.NSF/9a80cd5553c69ff588256d14005074ad/97c56add3adf94678825755900771691/$FILE/Draft_Upper%20CDA%20Basin%20FFS_Report_Executive_Summary%282%29.pdf).

Blackbird Creek Mine

Blackbird Creek Mine covers approximately 336 ha of private patented mining claims and 4,047 ha of unpatented claims, all within the Salmon National Forest, Idaho. Active mining for cobalt and copper occurred from the late 1800s to the 1980s, but the mine is currently dormant. Shaft and open pit methods were used and tunnels and waste rock piles occur along 13 km of Meadow and Blackbird creeks. Waste piles include as much as 2 million m^3 of material. Acid drainage from mines and spoil, and high levels of arsenic, copper, cobalt, and nickel, have been documented downstream in both surface water and sediments; copper levels exceeded USEPA water quality criteria (www.atsdr.cdc.gov/HAC/PHA/blackbird/bla_p3.html; www.epa.gov/superfund/sites/npl/nar1369.htm). Panther Creek, downstream of Blackbird Creek Mine, once supported fish, but by 1960, steelhead and Snake River spring/summer Chinook salmon were extirpated from it. Contaminants released at Blackbird Creek Mine were indicated as causal (www.darrp.noaa.gov/northwest/black/index.html). Blackbird Creek Mine is a registered public health hazard and a designated Superfund site.

Satellite image of the Berkeley Pit and tailings pond near Butte, Montana (from NASA). The long axis of the site is 7.5 km.

Montana

The Berkeley Pit

The Berkeley Pit operated from 1955 to 1985 as an open pit copper sulfide mine in Butte, Montana. The excavated mine pit is 542 m deep and 1.4 km across the rim. The pit filled with water once mining was completed, and it now contains about 1 trillion L of acidic (pH 2.7–3.4) water and metals (aluminum, arsenic, cadmium, copper, zinc; Twidwell et al. 2006). Over 193 km of the Clark Fork River and flood plain, and Milltown Reservoir, are contaminated by approximately 5 million cubic meters of contaminated mine tailings that washed downstream from Butte and collected behind the Milltown Dam (removed in 2008). Scientists with USEPA concluded that the metals behind the dam were contaminating local drinking water wells and causing large fish kills during high water events and ice scours (http://cfrtac.org/clarkforksite.php). Silver Bow Creek, which drains Butte, is nearly devoid of aquatic life (Hughes 1985). The pit and much of the surrounding mine facilities, including the Clark Fork River, form the largest Superfund site in the United States. Reclamation and remediation are ongoing and perpetual water treatment is required.

McLaren Mine

McLaren Mine in Cooke City, Montana, operated from 1933 to 1953 to extract gold, silver, and copper through use of heap leach cyanide methods (http://serc.carleton.edu/research_education/nativelands/ftbelknap/environmental. html). In 1950, a tailings dam failure on Soda Butte Creek released about 115,000 m^3 of metal laden effluent downstream. As much as a 60-cm-deep layer of tailings were deposited as far as 8 km downstream (Ecology and Environment 1988). Copper concentrations, documented as highly toxic to aquatic life (Sorensen 1991; Eisler 2000; Hecht et al. 2007), are elevated in macroinvertebrates and fish. Greater chronic metals toxicities occur in spring runoff compared to fall base flows (Nimmo et al. 1998; Marcus et al. 2001), indicating continued leaching. Soda Butte Creek was known for "fast fishing and large trout" during the late 1800s, but fishing opportunities declined with its water quality (USFWS 1979).

Zortman-Landusky Mine

The Zortman-Landusky gold and silver mine began operation in the 1880s. Mining was extended onto lands purchased from the Fort Belknap Indian Reservation in 1895 (Klauk 2009). Modern heap leach activity began in the late 1970s, and an environmental impact statement (EIS) was completed by the state in 1979, when the mine covered 109 ha. AMD impacts resulted from several spills, including a 2,953 L leak of cyanide-tainted solution from a containment pond in 1982. A rupture in a section of piping used in the mine's cyanide sprinkling system expanded the spill, releasing 196,841 L of cyanide solution onto lands and creeks (Klauk 2009). Local tap water revealed cyanide concentration levels above drinking water standards and the community's local water system was shutdown. Over the next two years, eight separate cyanide spills occurred (Klauk 2009). In September 1986, 75 million L of treated cyanide solution were released onto 7 ha of land when a solution pond was at risk of overflowing after a heavy rainstorm. The spills have contaminated streams and ground water throughout the area. By the late 1990s, total land disturbance reached almost 486 ha with about half on Bureau of Land Management (BLM) lands. In 1998, Zortman-Landusky, now consolidated with Pegasus Gold Ltd., filed for bankruptcy. Despite a $36 million settlement from a lawsuit filed under the Clean Water Act in 1996, the agencies had to file a notice of an $8.5 million reclamation bond shortfall with the bankruptcy court (Klauk 2009). Although $1.0 million of the shortfall was eventually awarded, the bankruptcy was finalized in December 2003, and BLM and the Montana Department of Environmental Quality assumed responsibility for water storage and treatment in perpetuity (BLM 2010). The BLM (2010) estimated that it will cost approximately $528,000/y to manage the site. In addition, the state expects to spend $240,000 annually on AMD treatment through 2017, and has established a fund to pay for treatment beyond 2017.

Nevada

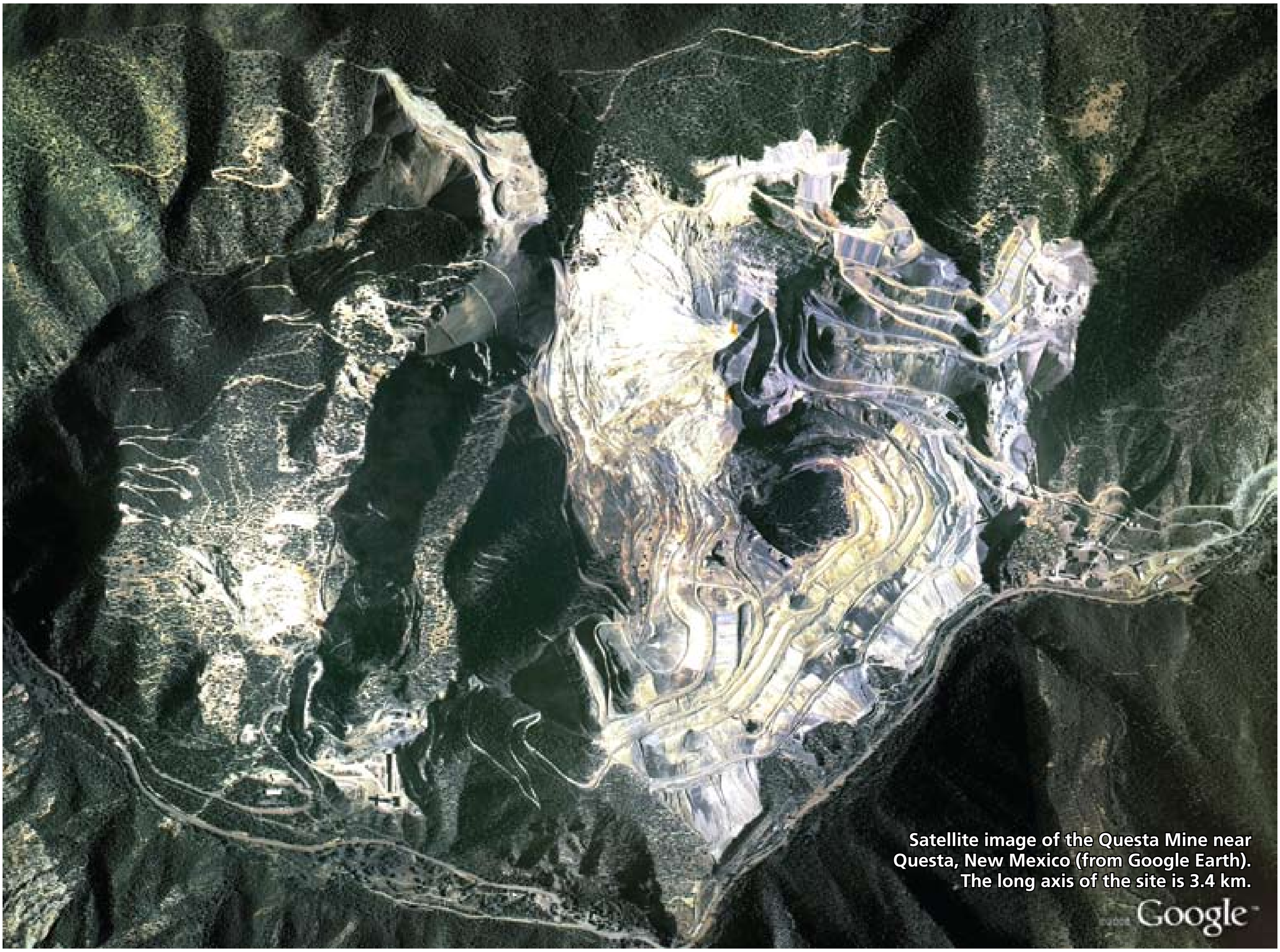
Caselton Mine

The Caselton Mine in Lincoln County began production in 1863 for silver, gold, lead, zinc, copper, and manganese. Part of the site continues to be marginally active, but most of it has been abandoned (IAMLET 1999). The value of metals produced was approximately $130 million, and approximately 1,147,000 m^3 of tailings remain, with an estimated cost of $11 million for on-site reclamation. That estimate does not include downstream treatment of contaminants.

New Mexico

Questa Mine

The Questa Mine Superfund site is located northeast of Santa Fe, and includes an active molybdenum mine, mill, tailings ponds, and tailings pipeline, as well as the Red River (USEPA 2010). The open pit mine opened in 1965 and the lower 13 km of the Red River were deemed "dead" by the New Mexico Water Quality Commission in 1994. Numerous pipeline breaks, AMD from the tailings ponds, aluminum, arsenic, cadmium, chromium, cobalt, fluoride, iron, lead, manganese, sulfate, and zinc have



Satellite image of the Questa Mine near Questa, New Mexico (from Google Earth). The long axis of the site is 3.4 km.

contaminated ground water and the Red River floodplain. Such contaminants threaten the Red River fisheries for brown trout (*Salmo trutta*) and cutbows (*O. clarki* x *O. mykiss*), the endangered Rio Grande cutthroat trout (*O. c. virginalis*), and a rainbow trout hatchery.

Oregon

Formosa Mine

The Formosa Mine (copper, zinc, thorium) on Silver Butte Creek near Riddle operated from 1990 to 1993. The mine has contaminated 18 miles of the Umpqua River watershed in western Oregon (USEPA 2007). The mine currently releases approximately 19 million L of AMD annually, containing up to 13,000 kg of dissolved copper and zinc, metals known to be highly toxic to fish (Dethloff et al. 1999; Baldwin et al. 2003). Consuming fish from the system poses a health risk to humans. Metals pollution is eliminating prime habitat for coho salmon (*O. kisutch*) and steelhead. Aquatic insects have disappeared from the upper reaches of the creek.

Utah

Atlas Mine

The Atlas Mine, located near Moab along the Colorado River, opened in 1952 as a uranium mine. The mine closed in 1984 but left an approximately 178 ha waste site and a 53 ha (16 million ton) tailings pile in the floodplain that leached into ground water and the Colorado River, creating a dead zone. Uranium concentrations in the dead zone are 1,660% greater than background levels. Flooding of the site had the potential of further contaminating the water supplies of millions of downriver humans. The U.S. Geological Survey observed 100% mortality of caged fish placed into the dead zone because of ammonia concentrations 750 times acutely lethal levels. The U.S. Fish and Wildlife Service considered leaching from the tailings as jeopardizing four endangered fish species: humpback chub (*Gila cypha*), bonytail (*G. elegans*), Colorado pikeminnow (*Ptychocheilus lucius*), and razorback sucker (*Xyrauchen texanus*). The tailings removal and burial began in 2009 at a cost of approximately $1 billion and are projected to require 20 years. The mine operator had posted a $5 million reclamation bond, and filed for bankruptcy (http://healutah.org/news/; http://grandcanyontrust.org/utah/uranium_history.php).

Washington

Midnite Mine

The Midnite Mine was an open-pit uranium mine on the Spokane Indian reservation in eastern Washington, and operated from 1955 to 1981. The Dawn Mill site, just off the reservation, also processed uranium. In the 1990s, both sites were found to be leaking radioactive metals, metals, and AMD into ground water and neighboring streams, including Blue Creek, which drains to Lake Roosevelt, the Columbia River reservoir behind Grand Coulee Dam. Blue Creek is used for spawning and rearing by rainbow trout, Paiute sculpin (*Cottus beldingi*; a species of concern in Washington), and other fishes (USEPA 2009a). Midnite Mine is currently an active Superfund site.

Holden Mine

The Holden Mine, in the Okanogan-Wenatchee National Forest in Chelan County, eastern Washington, operated from 1938 to 1957. It was one of the largest copper mines in the United States, and zinc, silver and gold were also mined. The AMD and metals leach into Railroad Creek, a tributary to Lake Chelan (Johnson et al. 1997). Risks to aquatic life include degradation of surface water quality and streambed armoring. Additionally, spoil piles along stream banks pose a risk to the aquatic community. A flood in 2003 required an emergency cleanup (www.fs.fed.us/r6/wenatchee/holden-mine/flood-damage-2003.shtml). The Holden Mine is an active Superfund site.

Wyoming

Smith-Highland Ranch Mine

The Smith-Highland Ranch Mine is a uranium mine near Douglas in northeast Wyoming that began operations in 1988. In 2008, the Wyoming Department of Environmental Quality (WDEQ) issued a notice of violations to the mine operator for 80 spills over multiple years, pond leaks, well casing failures, failure to restore ground water quality, and a grossly inadequate reclamation bond. Despite those concerns with contaminating ground water, mine self-monitoring, and inadequate WDEQ oversight, the mine has been allowed to continue to operate (http://trib.com/news/state-and-regional/article_b8f9b03a-d250-51f5-a1fc-f34646cfc567.html; www.powertechexposed.com/Cameco_Wyo_mine_permit_violations.htm).

An example of possible future mining impacts

The preceding examples demonstrate fisheries impacts from mining and the poor track record for maintaining water quality suitable for aquatic life (Maest et al. 2005; Kuipers et al. 2006), leading to concerns for new mines and a continuing legacy of mineral extraction trumping all other uses of public land. For example, the Pebble Mine claim on Alaska state lands in the Bristol Bay watershed is part of a massive low-grade porphyry copper sulfide deposit also containing gold and molybdenum. Its development is projected to require an open pit mine (~6 km^2 in area and ~490 m deep), an underground mine, dams at or above 200 m high, a ~160 km long haul road and slurry pipeline, development of a port facility on Cook Inlet for fuel and concentrated mineral storage, and 1.1 billion L of water annually (www.dnr.alaska.gov/mlw/mining/largemine/pebble/2006/damaap.pdf; www.dnr.alaska.gov/mlw/mining/largemine/pebble/2006/swutorig.pdf; www.dnr.alaska.gov/mlw/mining/largemine/pebble/2006/gwsfkfinal.pdf). The region that contains the Pebble copper deposit has porous alluvial soils, abundant ground and surface water, interconnected watersheds, undefined seismic faults, significant seismic activity, little buffering, and a high concentration of sulfides that are known to produce AMD (USFS 1993; Northern Dynasty Mines Inc. 2005; HDR Alaska and CH2M Hill 2008a,b; http://earthquake.usgs.gov/eqcenter/recenteqsus/Maps/special/Alaska.php; Jennings et al. 2008).

The Pebble prospect conditions have serious implications for fisheries. Dissolved copper concentrations as low as 2–10 ug/L above background can alter the olfactory-mediated survival and migration of salmonids (Hecht et al. 2007; Sandahl et al. 2007). The waters draining the Pebble copper deposit are essential to spawning, incubating, rearing, and migrating salmon and non-salmonids, and drain into waters supporting diverse Bristol Bay fisheries. Bristol Bay is home to the world's largest wild sockeye salmon (*O. nerka*) fisheries, and sustains healthy productive fisheries of other salmonids, herring, and crab. The local seafood industry employs about 10,000 people annually; gross earnings reported in 2007 were over $100 million in international sales (www.sf.adfg.state.ak.us/Statewide/economics/). A 2007 study of sportfishing economic impacts in Alaska indicated expenditures of $1.4 billion dollars generating 15,879 jobs, of which, $989 million and over 11,000 jobs were attributed to the southcentral region which includes Bristol Bay (www.sf.adfg.state.ak.us/Statewide/economics/). The Bristol Bay exvessel commercial salmon fishery has a 20-year estimated average annual value of $125.7 million ($123.1 million for sockeye; Sands et al. 2008). National catch statistics for sockeye salmon alone (mostly from Bristol Bay) indicated an exvessel value of over $7.8 billion between 1950 and 2008 (www.st.nmfs.noaa.gov/st1/commercial/landings/gc_runc.html). Alaska Native peoples have relied on annual salmon returns to the rivers draining the Pebble copper deposit for subsistence for thousands of years; salmon still comprise 60–80% of their total subsistence harvest, which for the last 20 years has averaged over 100,000 salmon annually from the Nushagak and Kvichak drainages alone (Fall et al. 2006; Sands et al. 2008). The Pebble copper deposit lies under state land straddling both the Nushagak and Kvichak drainages, is adjacent to Lake Clark National Park and Preserve, is about 24 km upgradient of Lake Iliamna where millions of sockeye fry rear annually, and is in the headwaters of the Nushagak, a major Chinook salmon producer. The Nushagak and Kvichak river drainages have produced about 50% of all commercially harvested sockeye salmon from Bristol Bay for 125 years (ADFG 2008a,b; Fair 2003). Given the importance of sustainable fisheries in Bristol Bay and its drainages, it seems advisable to mount an ecologically and statistically defensible surveying program in the region, and to make the study designs and all data produced from surveying the region publicly available for independent peer review.

Given the history of hardrock mining documented above, the risks to fisheries like those in the Bristol Bay drainage are high. The value of these fisheries, and the livelihoods of those who depend on them, should be considered when making decisions about land use. However, the Mining Law of 1872 still maintains mineral extraction as the highest priority use of federal lands and the BLM is considering opening 0.5 million ha of federal lands around Pebble to mining, which would further exacerbate the threat to the fishery. As Senator Lee Metcalf explained in his address to the North American Wildlife Conference in 1974, the Mining Law of 1872 is the "only law that puts the land use decision entirely in the hands of the developer" (Bakken 2008). Attempts to change the legislation in the 1990s failed due to powerful corporate interests and public apathy. An update to the Mining Law of 1872, signed by Ulysses Grant, is long overdue.

Future policy needs

Healthy sustainable fisheries support important local and national economies and depend on clean water and healthy watersheds. The examples presented, along with a wide array of other scientific evidence concerning hardrock mining, have demonstrated frequent incompatibility of hardrock mining with conservation of important fisheries resources due to outdated and inadequate regulations and policy. Although the American Fisheries Society has a surface mining policy (#13; www.fisheries.org/afs/policy_statements.html) in place, we recommend that the policy be revised to address more thoroughly the potential impacts of hardrock mining on fish and aquatic ecosystems. More importantly, and because hardrock mining is a vital industry, we recommend that the U.S. Congress revise the Mining Law of 1872 to:

1. **Establish clear environmental standards.** Specific standards for environmental protection need to be strengthened and elucidated within mining law, including:
   a. ***Reclamation.*** Mine sites should be reclaimed to sustain uses conforming to the applicable land use plan of the region, not just pre-existing, degraded conditions. Concurrent reclamation of mined lands prior to expanding onto undisturbed land can reduce overall impacts as well as provide data on the efficacy of the proposed reclamation plan. Such reclaim-as-you-go programs increase the probability that the proponent will cover the cost of reclamation before the mining operation shuts down.
   b. ***Fish and wildlife protection.*** Habitat and fish and wildlife assemblages should be restored to pre-mining conditions, at a minimum.
   c. ***Surface and ground water protection.*** Current federal law does not adequately protect ground water from mining pollution and the requirements of mine reclamation are insufficient to maintain compliance with state and federal water quality standards. Operations should minimize damage to surface and ground water resources, restore to at least pre-mining hydrological conditions, and ensure compliance with water quality standards.
   d. ***Revegetation.*** Mined areas should be reseeded and planted with sufficient vegetation and success should be measurable and monitored. Native species should be encouraged and noxious species controlled.
   e. ***Prohibition of perpetual pollution.*** Before mining ceases, mine operators should meet water quality criteria required to protect desired aquatic species without the permanent treatment of water.
   d. ***Mitigation.*** Mitigation proposals should be accompanied by clear success/failure measurement criteria and clearly defined alternative(s) that are triggered if the proposed mitigation fails. When ranking mitigation alternatives, the costs and benefits of the potential environmental impacts of each scenario should be part of the economical feasibility analysis.
2. **Protect special places.** The U.S. government currently interprets mining as the highest priority and best use for public lands based on the Mining Law of 1872. However, many places are of significant environmental value and should deserve special protections.
   a. ***Designate special lands as off-limits to hardrock exploration and development.*** Wilderness study areas, lands recommended for wilderness designation, sacred sites, areas of critical environmental concern, lands supporting highly valued or ESA-listed fish or wildlife populations, roadless areas, lands in the Wild and Scenic River System or recommended for such, and lands administratively withdrawn or segregated should be off limits to mineral exploration and development that would directly or indirectly affect them.
   b. ***Allow land managers to appropriately value mining relative to competing uses of public* land.** Land managers should be able to weigh competing land uses and consider the impacts of mining and the potential for reclamation to a desired state before mine approval. No mine should degrade the environment, public health, or public safety. Land managers should have the ability to deny permits when appropriate or to include appropriate requirements to protect the environment for approved operations.
3. **Initiate fiscal reform to increase permittee financial responsibility.** In 2000, the U.S. Bureau of Land Management estimated $982 million worth of hardrock minerals were excavated from public lands, yet the mining industry paid no royalty on those minerals. Fiscal reform is needed to aid in restoring damaged watersheds, and should include:
   a. ***End patenting.*** Under the Mining Law of 1872, an area about the size of Connecticut valued at over $245 billion dollars has been patented for far less than the land value.
   b. ***Establish royalty fees.*** Fees for new and existing mines similar to those paid by the fossil fuel industry (e.g., 8%–12.5%) should be established and used for land and water rehabilitation.
   c. ***Statutorily ensure reclamation bonding.*** Adequate reclamation bonds with clear clean-up standards are needed to protect both the environment and taxpayers. Estimated clean-up liability for operating mines is estimated to exceed $12 billion to taxpayers because of inadequate bonds.
   d. ***Establish regulatory fees.*** Fees are needed in the permitting process for effectiveness monitoring, enforcement infrastructure, and research.
4. **Create funds to clean up abandoned mines.** No dedicated federal funds currently exist to clean up abandoned mine sites. A royalty fund of $32–72 billion should be established to clean up abandoned mine sites. A program should be clearly developed and implemented to evaluate, prioritize, and fund those projects.

5. **Improve mine oversight and environmental protection.** Self-monitoring and self-reporting by the mining industry has frequently failed to protect waters and fishery resources because of irresponsible mining practices. Compliance with the Clean Water Act and state water quality standards must be achieved, including implementation of agency permit requirements and conditions, monitoring associated with National Pollution Discharge Elimination System (NPDES) permits, and other applicable regulations. Industry oversight from initial baseline studies to mine closure is needed, including:

   a. ***Independent peer review from exploration to closure.*** Annual technical reports and data should be prepared by independent mining consultants and released directly to the public as well as state and federal oversight agencies for review, critique, and improvement. Inadequacies in baseline studies and monitoring programs (including study design, site-scale design, standard methods, and indicators) should be documented and addressed (Hughes et al. 2000; Hughes and Peck 2008; Bonar et al. 2009). Agency recommendations should be considered and integrated or the status quo defended.
   b. ***Independent effectiveness monitoring.*** Independent or agency monitoring of water and sediment quality, flow regime, physical habitat structure, and biological assemblages (fish, benthic macroinvertebrates, algae, riparian vegetation) should be conducted at least during high and base flows as part of the mine permit and paid for by the permitee. Monitoring should be independent of the agencies responsible for mineral leasing, because of their roles in encouraging mining.
   c. ***Inspections.*** Unannounced inspections should be mandatory. Water quality samples should be split for independent analyses by independent laboratories, with oversight by responsible agencies for quality control. Regulatory agencies should be adequately funded to conduct rigorous and frequent inspections. In addition, the right of the public to reasonably request inspections should be guaranteed.
   d. ***Cessation of work.*** Failure to successfully address mining violations should require ceasing operations until appropriate remediation is addressed and implemented.
   e. ***Track violators.*** Operators (including firms and persons) that have a history of serious violations or are currently seriously violating laws should be ineligible for new or renewed permits and liable for criminal proceedings. Further, additional permits or permit renewals should not be considered until reclamation at other sites has been deemed appropriate and successful by the regulatory agencies and stakeholders involved.
   f. ***Right to sue.*** Citizens should have the right to file suit in federal and (or) state courts when operators or government agencies fail to implement and monitor best management practices.
   g. ***Risk analysis.*** Unanticipated events that lead to the release of metals, chemicals, dust, and debris pose serious risks to aquatic biota. Mine permitting and reclamation insurance should be developed within the context of risk assessment that takes into account landscape properties, climate, earthquake hazards, and extraction and reclamation methods.

6. **Fund research needs.** The National Academy of Sciences (1999) and USEPA (2004) recommended an aggressive and coordinated research program related to the environmental impacts of hardrock mining. A better understanding of mining practices, problems, and solutions is needed to prevent water quality degradation, guide rehabilitation of contaminated watersheds, and mitigate the effects of future hardrock mining.
7. **Follow the precautionary principle.** Time and again we have learned that it is more costly and uncertain to rehabilitate natural resources than it is to protect them. Given the inability of planners and engineers to prevent catastrophic failures, it is incumbent on the professionals that work with fisheries, wildlife, and other resources to carefully scrutinize any proposed new developments. As we write this piece, hundreds of cubic meters of oil are gushing daily from the seafloor in the Gulf of Mexico and drifting shoreward, in an event that was apparently not anticipated, and for which there were no adequate contingency plans. Recent history is replete with similar engineering shortcomings (e.g., Santa Barbara and *Exxon Valdez* oil spills, Tacoma Narrows and Minneapolis bridge collapses, Three Mile Island and Enrico Fermi nuclear plant meltdowns, *Challenger* and *Columbia* space shuttle explosions, Teton and Buffalo Creek dam collapses, Consol and Upper Big Branch mine explosions, Baie Mare and Aznalcollar mine spills). History teaches us that once initiated, mining projects continue no matter how serious the violations of permits. Therefore, the permitting process should assume that stated levels will be exceeded, and that catastrophes and spills will occur. The risks and benefits should be weighed accordingly following rigorous examination of mining and infrastructure plans, economic evaluation, ecological surveys, and peer review of all data.

Summary

The U.S. General Mining Law of 1872 allows mining operators to enter, explore, and begin the permitting process for a claim, but does not require a commitment to return the lands and waters to a state supporting aquatic life. Most mining practices require water in large quantities for some aspect of extraction, processing, or transport of the mined material and its byproducts. Therefore aquatic systems are heavily altered directly, indirectly, and cumulatively by mining. History has shown that the legacy impacts of mining are often significantly more persistent and expensive than those observed during active mining. Just as no mining company would consider it feasible to go back to nineteenth century mining practices and technology, U.S. citizens should expect mining projects to meet modern scientific standards by employing rigorous scientific assessment of all potential impacts, and by providing public access to all information gathered in those assessments in sufficient time for scientific peer review.

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